DOCUMENT RESUME

ED 173 651 CE 022 320

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TITLE Water Treatment Technology - Filtration.
INSTITUTION West Virginia Research Coordinating Unit for Vocational Education, Huntington.; West Virginia State Dept. of Education, Charleston. Bureau of Vocational, Technical, and Adult Education.; West Virginia State Dept. of Health, Charleston.
SPONS AGENCY Office of Education (DHEW), Washington, D.C.
PUB DATE Dec 78
GRANT G007603801; H007800069
NOTE 59p.; For related documents see CE 022 313-324 ; Not available in hard copy due to marginal legibility

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS Educational Objectives; Evaluation Methods; Individualized Curriculum; Instructional Materials; *Job Skills; Learning Activities; Public Health; Trade and Industrial Education; *Utilities; Water Resources
IDENTIFIERS *Filtration; *Water Treatment; West Virginia

ABSTRACT

One of twelve water treatment technology units, this student manual on filtration provides instructional materials for six competencies. (The twelve units are designed for a continuing education training course for public water supply operators.) The competencies focus on the following areas: purposes of sedimentation basins and flocculation units, rapid sand gravity and pressure filters, filter faults, backwash procedures, backwashing frequency, and backwashing filters. For each competency, student objectives, resources (information sheets and appendix materials), learning activities, and evaluation activities are provided. The appendices contain information sheets on rapid mixing and flocculation, sedimentation, filtration, and chemical coagulation and flocculation. Generally, an evaluation form and answer key are provided for each competency. (JH)

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Water Treatment Technology

FILTRATION

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December, 1978

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

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U.S.O.E. Original Grant No. G007603801 &
U.S.O.E. Field Test Grant No. H007800069

CE 022 320

FILTRATION

EVALUATOR'S COPY

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ACKNOWLEDGEMENTS

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EVALUATOR'S INSTRUCTIONS

Name _____

Address _____

_____

Phone _____

This is your EVALUATOR'S COPY of the FILTRATION unit. It contains all of the materials received by the operators who will be working on the unit. It also contains *answer keys* and *directions* for the evaluation of each Competency. For each Competency Sheet, there is a COMPETENCY, a list of RESOURCES, LEARNING ACTIVITIES, and EVALUATION ACTIVITIES.

Your student operators will call you when they are ready to be evaluated. An operator may complete the evaluations in *any* order. S/he may choose to complete one at a time, or several at one time. *It is up to you and each operator to set convenient schedules for the evaluations.* It is important that the operators learn the skills listed in each competency. It is <u>your</u> job to be sure the operators can perform the competencies.

If an operator does <u>not</u> complete an evaluation correctly, s/he may try again later after practicing the skills. It would be helpful for you to tell the operators just how they should improve their knowledge and skills in order to complete the evaluation successfully. Be sure to call if you have any questions.

This package contains:

- - - - - - FILTRATION unit

- - - - - - Evaluation Forms for each Competency

You will receive instructions as to where to send the completed evaluation forms. Please be sure that the operator's name and your name are on the forms, as well as the date on which the evaluation was performed.

INSTRUCTIONS FOR THE STUDENT OPERATOR

The FILTRATION unit contains six competencies. A "competency" is a skill that is necessary for good on-the-job performance. Each competency in this unit is necessary for you to perform on the job according to the West Virginia Department of Health. There is a Competency Sheet to help you understand each competency.

DIRECTIONS FOR COMPLETING THE UNIT:

1. Read each Competency Sheet carefully. Every Competency Sheet contains:

   COMPETENCY
   Objectives
   RESOURCES
   LEARNING ACTIVITIES
   EVALUATION ACTIVITY (IES)

2. After reading the whole Competency Sheet, you should understand what will be expected of you.

3. Do the LEARNING ACTIVITIES that you think will help you the most. This may include reading some of the RESOURCES which have been included with the unit.

4. If you need additional help, ask an operator in your plant for assistance, or call your evaluator; he's there to help you.

5. When you are ready to complete the EVALUATION ACTIVITY for one or more competencies - - call your evaluator. The two of you will schedule the best time for your evaluation.

   a. If you complete the evaluation correctly, go on to the next competency.
   b. If you do <u>not</u> complete the evaluation correctly, your evaluator will tell you what your mistakes were. You must go back and practice your skills and read the RESOURCES again. Call your evaluator when you are ready to try again. *You must wait at least one week before being re-evaluated on a competency.*

6. When you complete all your evaluations correctly you will receive a Certificate of Accomplishment and 1.2 Continuing Education Units of Credit.

7. If you want to go on to another unit, contact your evaluator for the materials. The procedure will be similar for all units.

AN EXPLANATION OF CONTINUING EDUCATION UNITS

For student operators in the OPERATOR-IN-TRAINING category who will be taking the certification examination for Class I, this course is an opportunity to increase your knowledge and competence in the treatment of water for human consumption. Successful completion of the manuals will also, it is hoped, make passing the certification exam much easier. The Continuing Education Units which you will get by taking this course will not decrease the minimum one year operating experience requirement for a Class I certificate.

For student operators who now hold a Class I certificate, the completion of all twelve manuals in the course will reduce the currently required three years of total operating experience for Class II certification by approximately four months. Thus, if you complete the course, you will need only two years and eight months of total operating experience before you take the Class II exam.

Here is a listing of the Continuing Education Unit (CEU) value of each of the manuals.

Manual	CEU Value
General Plant Operation	1.4
Taste, Odor, and Color	0.6
Chemistry/Bacteriology	2.5
Chlorination	2.5
Fluoridation	0.6
Filtration	1.2
Hydraulics	0.6
Distribution Systems	1.2
Pumps	0.6
Wells	1.0
Cross Connections	0.4
Springs	0.4
Total	13.0

For comparison with other types of training previously available, the CEU conversions below are given.

Public Water Supply Operator's Short Course (given by State Department of Health Personnel)	4 CEUs
One Semester Hour of College Credit	1.5 CEUs
One Year of College Credits (30 semester hours)	45 CEUs

COMPETENCY: Describe the purpose of sedimentation basins and flocculation units and explain how they work.

Objective: Describe how the sedimentation *(or "settling")* basin contributes to the filtration process.

Objective: Describe how flocculation units contribute to the filtration process.

RESOURCES:

(a) Chapter 5, Water Treatment Plant Design, published by The AWWA, 1969, pp 65-76. *-Pink Appendix-*

(b) Water Treatment Plant Design, published by The AWWA, 1969, pp 77-81 *-Green Appendix-*

(c) Manual of Instruction for Water Treatment Plant Operators, New York State Department of Health, Health Education Service, P.O. Box 7283, Albany, N.Y. 12224, Chapter 7 *-Gold Appendix-*

LEARNING ACTIVITIES:

(a) Read the Resources listed above to find more information about settling basins and flocculators.

(b) Take a "tour" of your own treatment plant. Check the following points:

-At what point in the treatment process does flocculation take place?

-How is chemical coagulation related to flocculation?

-What type of flocculation equipment is used in your treatment plant?

-What is the difference between "mixing" and "flocculation"?

-What is the *purpose* of flocculation?

-What is the *purpose* of sedimentation?

-What is the average sedimentation detention time (amount of time it takes for water to pass through the sedimentation basin)?

-What is the velocity per minute of water passing through the sedimentation basin?

-What does *"short circuiting"* in the sedimentation basin mean? How can it be avoided?

-How is the sedimentation basin in your treatment plant cleaned? How often is it cleaned?

-Where does the water go after leaving the sedimentation basin?

EVALUATION ACTIVITIES: (a) Complete Evaluation Form #35. It contains questions about flocculation and sedimentation. You may not use references.

(b) Make a sketch of the process water as it goes through your plant from the beginning of flocculation to the end of sedimentation. Label the parts of your drawing. Describe to your evaluator:

1. The type of flocculators used in your treatment plant.
2. Approximate detention time in the sedimentation basin.
3. The approximate velocity per minute of water moving through the sedimentation basin.
4. How the sedimentation basin at your treatment plant is cleaned.
5. How "short circuiting" can be avoided.
6. Where the water goes after leaving the sedimentation basin.

(Filtration #35)
Evaluation Form
EVALUATOR'S COPY
Part I

Operator _____

Evaluator _____

Date _____

Directions: *For each item below write "TRUE" or "FALSE" in the space provided. If you answer "FALSE" write the correct answer on the lines under the question.*

1. *False* "Mixing" and "flocculation" are the same thing.
Mixing is the process of rapidly mixing in chemicals. Flocculation is gentle agitation of the treated water.

2. *False* Sedimentation usually comes before flocculation.
Sedimentation follows flocculation so that the floc can be settled out of the treated water.

3. *False* The main purpose of flocculation is to mix in the chemicals that treat the water.
Flocculation is too slow to adequately mix chemicals. The purpose of flocculation is to form floc.

4. *True* "Short circuiting" in the sedimentation basin should be corrected.

5. *False* For best results, water should move quickly through the sedimentation basin.
Water moves very slowly through the sedimentation basin to allow time for the floc to settle.

6. *True* Sedimentation makes the filtration process more efficient.

COMPETENCY: Sketch, label, and describe a rapid sand gravity filter and a rapid sand pressure filter.

Objective: Sketch and label a rapid sand pressure filter. Describe how this type of filter works.

Objective: Sketch and label a rapid sand gravity filter. Describe how this type of filter works.

RESOURCES:

(a) TYPES OF FILTERS, Resource Sheet.

(b) FILTRATION *-Yellow Appendix-*

LEARNING ACTIVITIES:

(a) Read the Resources listed above to find information about filters.

(b) Determine the type of filter(s) used at your treatment plant. Pressure or gravity type?

(c) Your treatment plant may use some filtering medium other than sand, such as anthracite or diatomaceous earth*. What is the *effective size* and the *uniformity coefficient* of the sand used at your treatment plant?

(d) Using observation and information from your plant operator draw a sketch of the type of filter(s) used in your treatment plant. Include and label layers of water, sand, gravel, tile, etc. How thick (deep) is each layer? At what rate does water pass through your filter?

(e) Draw a sketch of the type of filter not used in your treatment plant (pressure or gravity type). Both types of filters are used in West Virginia, so it is important that you become familiar with the construction and operation of both types of filters.

*"Sand" will be used as the term to describe filtering media for this unit. Substitute your media for "sand" if your plant uses another medium.

EVALUATION ACTIVITY: You will be expected to draw two sketches. One of a rapid sand gravity filter and one of a pressure filter. Be sure to include and label all parts and all the layers of medium for each.

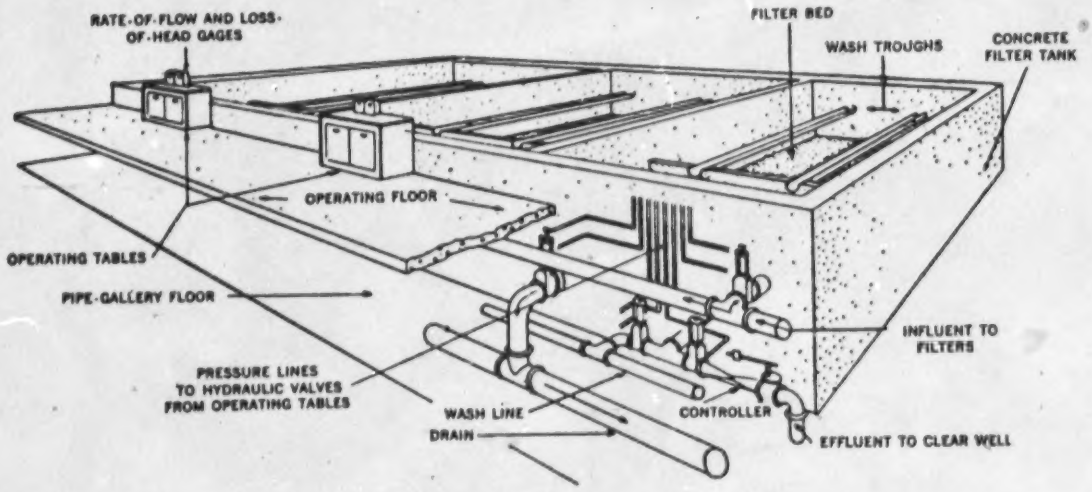
TYPES OF FILTERS*

A. *Slow Sand Filters*. Slow sand filters have fine-grain sand and low filtration rates. They are usually used when coagulation is not included in the treatment process. Their capacity is about 2 to 10 mgd per acre of filter surface. Use of slow sand filters has been practically discontinued because of their high cost per unit of capacity and the labor required to clean them.

B. *Rapid Sand Filters*. Rapid sand filters are now universally used in modern treatment plants. There are two types: gravity and pressure.

Gravity Filters (See Figure 1). Gravity filters are open-top rectangular concrete boxes about 10 feet deep. An underdrain system at the bottom is covered by gravel. A 24-30 inch layer of fine sand is on top of the gravel. Gravity filters usually filter about 2 gpm per square foot of filter-bed area.

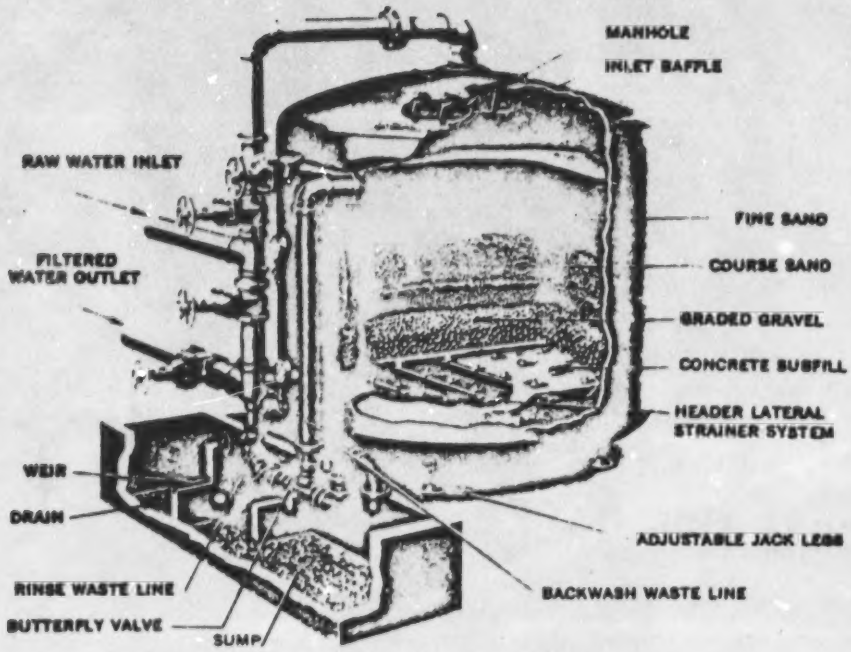
Pressure Filters (See Figures 2 and 3). Pressure filters have the filter bed enclosed in a pressure vessel. Water is pumped in and forced through the filter *or* drawn into the vessel and through the filter by a suction pump. They can be installed with the tanks set either vertically or horizontally. They operate on the same principles and at the same rate as gravity filters.



Battery of Three Gravity Type Rapid Sand Filters.

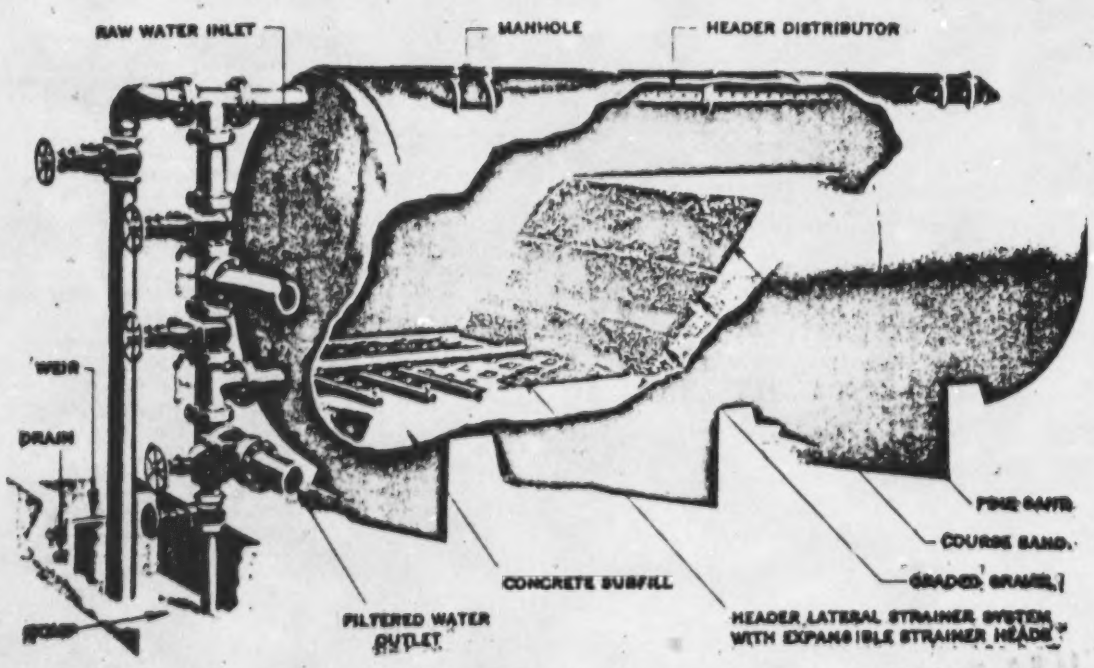
Fig. 1

*Source: Adapted from Maintenance and Operation of Water Plants and Systems, Department of The Air Force, Air Force Manual No. 85-13, June 15, 1968, pp. 141-142.



VERTICAL PRESSURE FILTER

Fig. 2



HORIZONTAL PRESSURE FILTER

Fig. 3

COMPETENCY: Demonstrate the ability to inspect your filter for cracks, mud balls, and other imperfections.

Objective: Describe how cracks and mud balls are formed and how they affect filtration.

Objective: Describe how to identify cracks, mud balls, and other imperfections in your filter.

Objective: Demonstrate the ability to rid your filter of cracks, mud balls, and other imperfections.

RESOURCES:

(a) Resource Sheet, "Filter Inspection".

(b) FILTRATION *-Yellow Appendix-*

LEARNING ACTIVITIES:

(a) Read the Resources listed above to find information about inspecting your filter.

(b) Inspect the filter(s) at your treatment plant. Look for mud balls, cracks, and signs of air binding and clogging.

Check to see how long it has been since each filter has been backwashed.

If mud balls, cracks, etc. are apparent, do whatever is necessary to clear the filter bed.

EVALUATION ACTIVITIES:

(a) Complete Evaluation Form #37. It contains questions about inspecting your filter(s). <u>You may not use references</u>.

(b) Demonstrate for your evaluator how to inspect a filter for imperfections. Explain what you would do if you found: mud balls, cracks, air binding, and clogging.

Filter Inspection

1. **MUD BALLS-** If a filter bed is not backwashed correctly, sand grains and foreign matter begin to stick together. After awhile large clumps called *mud balls* are formed. They must be removed because they lower the efficiency of the filter bed. Surface washing usually breaks down mud balls. They can then be removed by backwashing.

   If your plant does not have surface wash equipment, mud balls can be removed as follows:

   (a) Wash filter bed *completely clean* every 2 to 3 weeks. Use about twice the usual amount of backwash to make sure the bed is thoroughly cleaned.
   (b) When wash water is clear, reduce rate until bed is expanded about 20% to 25%. This exposes mud balls on sand surface.
   (c) Remove the mud balls with a rake or mesh screen attached to a long handle.

2. **CLOGGING-** Usually filter sands become clogged only at the surface. They are restored to use by ordinary washing methods. Sometimes, however, the whole bed becomes clogged and caked. Then it cannot filter properly. This means the sand and gravel must be removed from the filter and thoroughly washed or replaced as may be needed.

   Causes of complete clogging:

   (a) Backwashing is incomplete or rate is too low.
   (b) Pretreatment is inadequate and water reaching the filter is too turbid.
   (c) Alum is deposited in filter bed because of improper coagulation and sedimentation.

   Locating clogged areas:

   (a) Sweep a rake through the sand bed while it is being backwashed. In places where there is resistance to sweeping, there are clogs.
   (b) Probe down to gravel bed during backwashing. An uneven gravel bed may mean that sand is clogged. Wash water cannot pass through

caked sand. It flows under the sand bed carrying fine gravel with it until it reaches unclogged sand. The displaced gravel builds up in mounds under unclogged areas. Mounds over 2 inches high are a sign of serious clogging.

3. AIR BINDING- Air binding occurs when pockets of air build up in the sand. It interferes with proper filtration as indicated by high loss of head.

Causes of air binding:

(a) Operating with insufficient water above the sand.
(b) Rapid fluctuations in head causing holes to be blown in the sand.
(c) Filling filter too rapidly when returning it to surface after washing.
(d) Allowing water level to drop below the surface of the sand bed when draining the filter for inspection.
(e) Release of dissolved oxygen in the water.

Remedies for air binding:

(a) Fill the bed *slowly* from the bottom through the wash water line, forcing the air out of the filter. Do this carefully to prevent violent agitation of the sand bed. Allow the bed to stand idle for several hours after filling.
(b) Keep the depth of the water in the top of the filter greater than the total loss of head through the filter before it is cleaned. This will prevent the development of a partial vacuum and air pockets. Usually, water should be about 5 feet above the sand. In most systems, this permits 7 to 9 feet loss of head before the filter begins to operate under a vacuum.
(c) Avoid wide fluctuations in head during operation which may cause holes to be blown in the sand.

4. LOSS-OF-HEAD GAUGE- The "loss of head" through a filter is the friction loss of the water through the sand bed and underdrains of the filter. It is measured as the difference between the surface of the water on the filter and the static operating level of

the water in a vertical tube on the discharge pipe of the filter. The loss-of-head gauge is operated by two floats. One float is at the surface of the water in the filter. The other float is at the static operating level of the water in the main under-drain pipe. The loss-of-head gauge measures the difference between the two elevations.

The loss-of-head gauge shows when a filter should be washed, and it also indicates:

(a) Cracks in the filter bed surface. Cracks let water pass through to the underdrain. This causes the loss of head to decrease suddenly. This is a serious condition because the water which passes through cracks is not properly filtered.
(b) Improper operation of the rate-of-flow controller. When the flow of water through the filter is not correctly controlled, the loss-of-head gauge gives an abnormal reading.
(c) Whether automatic effluent valves are functioning correctly. If mechanically operated valves do not open properly, water does not flow normally to or from the filter. That means the loss-of-head gauge would not register the normal loss of head.

(Filtration #37)
Evaluation Form
EVALUATOR'S COPY
Part I

Operator _____

Evaluator _____

Date _____

Directions: Write the word "TRUE" or "FALSE" next to each item. If you answer "FALSE" write the correct answer on the lines below the question.

1. *False* Mud balls do not affect the efficiency of the filter.
Mud balls should be removed as soon as they are spotted. They lower the efficiency of the filter.

2. *True* Very turbid water can cause clogging in the filter bed.

3. *True* Improper coagulation and sedimentation can cause alum deposits in the filter bed.

4. *True* Water can pass through cracks to the underdrain without being properly filtered.

5. *False* An uneven gravel bed means the filter is functioning properly.
An uneven gravel bed is a sign of clogging. It impairs the filter's functioning.

6. *True* Mud balls are made up of sand and other matter that sticks together.

7. *True* When a depression or crater appears in the sand, a large part of the sand bed may disappear through it.

8. *True* Filling the filter through the influent valve will cause air to be trapped in the sand.

COMPETENCY: Describe the purpose and step-by-step procedure for backwashing a filter in your treatment plant.

Objective: Describe the reasons for backwashing a filter.

Objective: Describe how to determine when a filter needs to be backwashed.

Objective: Identify and describe important filter equipment that is used during backwashing.

Objective: List the step-by-step procedure for backwashing a filter in your treatment plant.

RESOURCES:

(a) "Backwash Procedures", Resource Sheet I.

(b) "Filter Equipment", Resource Sheet II.

LEARNING ACTIVITIES:

(a) Read the Resources listed above to find information about the process of backwashing.

(b) If possible, observe an experienced operator in your treatment plant while s/he backwashes a filter. Observe the loss-of-head gauge before and after backwashing. Note the sequence in which valves are opened and closed.

(c) Using references, make a list of the steps involved in backwashing a filter. Be sure that you know the order in which to open and close the proper valves.

Practice listing the steps for backwashing using no references. Check to make sure you are correct.

EVALUATION ACTIVITY: Complete Evaluation Form #38. It contains questions about filter equipment, the purpose of backwashing, and the step-by-step procedure of backwashing. You may not use references.

"Backwash Procedures"

Note: Procedure will vary from filter to filter. Check manufacturer's instructions for backwashing.

(a) Close influent valve. Allow water in filter unit to drop to level of wash water trough.

(b) Close filter effluent valve.

(c) Open waste valve.

(d) Start wash water pump.

(e) Open wash water valve *slowly* to prevent upsetting the underdrain.

(f) Open surface wash agitator valve when wash water valve is about 30% open.

(g) Continue to wash until wash water flowing over into troughs is practically free of sediment. (The proper length of time to wash will vary from plant to plant and filter to filter.)

(h) Close surface wash agitator valve.

(i) Close wash water valve *slowly*.

(j) Stop wash water pump.

(k) Close waste valve.

(l) Open filter influent valve *slowly*.

(m) Open filter effluent valve.

FILTER EQUIPMENT*

A. *Rate Controller.* When a filter bed has just been washed water passes through it far too quickly. The rate must be controlled for efficient filtration. The effluent line must be throttled to reduce the rate of flow. As the filter bed becomes clogged the rate of filtration decreases. Then the amount of throttling must be reduced to keep the rate of filtration uniform. This is the purpose of the *rate-of-flow (or rate-) controller.* A constant and controlled rate of filtration is necessary. Changes in the filtering rate may cause breaks in the filter bed. This would allow water to pass through without being filtered. Also, increases in negative pressure under the filter surface may cause dissolved gases to be released causing air binding. *The total rate is obtained by multiplying the square feet area of the filter bed by the allowable rate (usually 2 gpm per square foot of filter area). The rate controller is then set for this total rate.*

B. *Loss-of-Head Gauge.* The loss of head through a filter is the friction loss of the water through the sand bed and underdrains. Loss of head is measured as the difference between the surface of the water on the filter and the static operating level of the water in a vertical tube on the discharge pipe of the filter. The loss-of-head gauge is operated by two floats. One float is at the surface of the water in the filter. The other float is at the static operating level of the water in the main underdrain pipe. *The loss-of-head gauge is the most important guide to filter operation.*

C. *Wash-Water Controller.* A rate-of-flow controller similar to the one controlling the filter rate may be used as a wash-water controller. Or a butterfly valve or a special type plug valve may be used to control the wash-water rate. The valve operating mechanism (or control) and a pressure gauge showing the pressure in the wash-water pipe line on the discharge side of the control valve should be located on the operating floor.

D. *Rate-of-Flow Indicator.* The rate-of-flow indicator measures the rate of water production by the filter. It usually consists of a venturi meter in the filter effluent line and an indicating instrument located on the operating floor. In some types of plant equipment it is combined with the loss-of-head gauge and the rate-of-flow controller metering devices.

*Source: Adapted from Maintenance and Operation of Water Plants and Systems, Department of the Air Force, Air Force Manual No. 85-13, June 15, 1968, pp. 145-148.

E. *Filter Operating Tables*. In small plants the valves used for operating the filters are operated by hand. The valve stems come up through the operating floor and are attached to valve stands. In large and more modern plants, electric, air, or hydraulic systems may operate the valves. Filter operating tables are for these types of systems. The controls for all the valves and the indicating and recording meters are installed in a separate operating table located on the operating floor.

F. *Hook Gauge*. The hook gauge is used to check the rate of filtration and washing. It is a series of vertical sharp pointed rods. The tips of the rods are set at 2- or 3-inch spacing. It is hung on the side of the filter. The time required for the water level to rise or fall between the points is recorded. The volume of water in the filter between the gauge point levels is easily calculated. The rate is determined from the time recording.

G. *Piping and Valves*. The filter piping is usually located in a pipe gallery. It carries the influent, effluent, and wash- and waste-water to and from the filter. Valves and piping are arranged so that some of the piping may be used for more than one purpose. The rate-of-flow controllers and metering units are installed in these pipe lines. Valves may be operated by hand, electrically, hydraulically, or pneumatically. At least one sleeve joint should be provided in each pipe line at each filter because of expansion and contraction. The pipe gallery should be well lighted, well ventilated, and provided with a floor drain or sump pump. All piping and valves should be kept painted at all times.

Operator _____

Evaluator _____

Date _____

Directions: Write "TRUE" or "FALSE" in the space provided for each item. If you answer "FALSE" write the correct answer on the lines under the question.

1. *True* The loss-of-head gauge indicates when the filter should be backwashed.

2. *False* A filter should be backwashed twice every day.
Not necessarily. A filter should generally be backwashed when loss of head reaches about 5-9 feet.

3. *True* Measuring sand expansion during backwashing is a way to tell if there is a loss of sand during backwashing.

4. *True* The rate-of-flow controller controls the filter rate when water is not being backwashed.

5. *False* The rate-of-flow indicator controls the rate of flow during backwashing.
The rate-of-flow indicator measures the rate of water production by the filter. The wash-water controller controls water during backwashing.

6. *True* High losses of head cause the sand to pack tightly.

EVALUATOR'S COPY

7. List below the step-by-step procedure for backwashing a filter:

(a) *Close influent valve. Allow water in filter unit to drop to level of wash water trough.*

(b) *Close filter effluent valve.*

(c) *Open waste valve.*

(d) *Start wash water pump.*

(e) *Open wash water valve slowly to prevent upsetting the underdrain.*

(f) *Open "surface wash agitator" valve when wash water valve is about 30% open.*

(g) *Continue to wash until wash water flowing over into troughs is practically free of sediment. The proper length of time to wash will vary from plant to plant and filter to filter.*

(h) *Close surface wash agitator valve.*

(i) *Close wash water valve slowly.*

(j) *Stop wash water pump.*

(k) *Close waste valve.*

(l) *Open filter influent valve slowly.*

(m) *Open filter effluent valve.*

COMPETENCY: Determine, on the average, how often the filter(s) in your treatment plant should be backwashed.

Objective: Describe what would happen if filters were not backwashed often enough.

Objective: Describe the effects of backwashing filters too frequently.

Objective: Determine how often filters in your treatment plant should be backwashed.

RESOURCES: (a) FILTRATION *-Yellow Appendix-*

LEARNING ACTIVITIES:

(a) Read the Resource listed above to find information on how to determine how often filters should be backwashed.

(b) Describe the effects of waiting too long to backwash a filter. How is filter efficiency affected? What problems can occur?

(c) Describe the disadvantages of backwashing a filter too frequently.

(d) Determine how frequently the filter(s) in your treatment plant should be backwashed for maximum efficiency. Check the manufacturer's directions for care and maintenance.

EVALUATION ACTIVITY: You will be expected to explain to your evaluator how often each filter in your treatment plant should be backwashed. Give your reasons for your answers. Describe what would happen if the filters were not backwashed often enough. Describe the effects of backwashing filters too frequently.

COMPETENCY: Backwash a filter in your plant for an appropriate amount of time while opening and closing the valves in the proper order.

Objective: Demonstrate your ability to determine when a filter needs to be backwashed.

Objective: Backwash a filter in your treatment plant performing all necessary procedures properly.

RESOURCES:

(a) "Backwash Procedures", Resource Sheet from Competency #38.

(b) Manufacturer's instructions for backwashing your treatment plant filter(s).

LEARNING ACTIVITIES:

(a) Review Competencies 35-39 and related Appendices.

(b) Under supervision of an experienced operator, practice backwashing the filter(s) in your treatment plant. Remember, you must know how long it has been since a filter has been backwashed and how often it should be backwashed for maximum efficiency. Use the filter manufacturer's instructions for backwashing.

EVALUATION ACTIVITY: While your evaluator observes you, backwash a filter in your treatment plant for an appropriate amount of time while opening and closing the valves in the proper order.

RAPID MIXING AND FLOCCULATION*

As a water treatment process, flocculation was unknown a century ago. So, also, were bacteria and viruses unknown. With the development of rapid sand filtration around 1885, it was immediately realized that with this method of filtration clear water could not be produced without flocculation. Experience has demonstrated that few bacteria and soil particles and almost no viruses are removed by passing unflocculated water through rapid sand filters.

The objective of coagulation and flocculation is to attain almost complete envelopment of suspended particles within the floc particles, and to condition the floc particles so that they will readily be removable in the subsequent processes of sedimentation, or filtration, or both.

Water treatment practitioners once used the word *coagulation* to refer to an entire process that included addition of chemical coagulants, dispersion, flocculation, and settling. Today, the chemist's definition of *Coagulation* is used: It is the driving together of colloidal particles by chemical forces. The process is speedy and occurs within seconds of the application of the coagulating reagent to the water. Because of this, intense mixing is necessary at the point of Chemical application in order to insure uniform chemical distribution and exposure of the fine particles in the water to the coagulating agent before the coagulation reaction is completed. This is the work of the rapid mix.

The term *flocculation* refers to the assembling of coagulated particles into floc particles. Flocculation may be partly a chemical bridging mechanism, enhanced by the use of substances like polyelectrolytes, but it is much slower, and more dependent on time and amount of agitation than is coagulation.

Coagulation and flocculation are greatly influenced by physical and chemical forces such as electrical charges on particles, exchange capacity, particle size and concentration, pH, water temperature, and electrolyte concentrations. These and other factors vary widely from place to place, and their influence and effects are not fully understood. Because of this, it is important to secure information on the behavior of the water to be treated in a proposed plant. This may be done by examination of records of adjacent plants treating similar water, and by laboratory testing using "jar test" techniques, followed by laboratory filtration.

*Source: Chapter 5, Water Treatment Plant Design, published by the American Water Works Association, 1969; pp. 65-76.

Equipment and Accessories

Power may be put into water to secure mixing either by mechanical agitators or by use of gravity in baffled basins. In either case, the power needed is the same. Baffled basins may be horizontal (around the end) or vertical (over and under). The latter provide more continuous turbulence but are difficult to clean.

Mechanical agitators consist of two general types: rotary units, and reciprocating units that are usually operated through a crank mechanism. Types of agitator units and the flow patterns they create are illustrated in Fig. 1. Walking-beam type units may be installed without underwater bearings. Paddle and reel type units tend to impart a general rotary motion to the water, as well as some internal turbulence. Paddle and reel design details are available from manufacturers. Turbine and axial flow impellors are designed as pumping units.

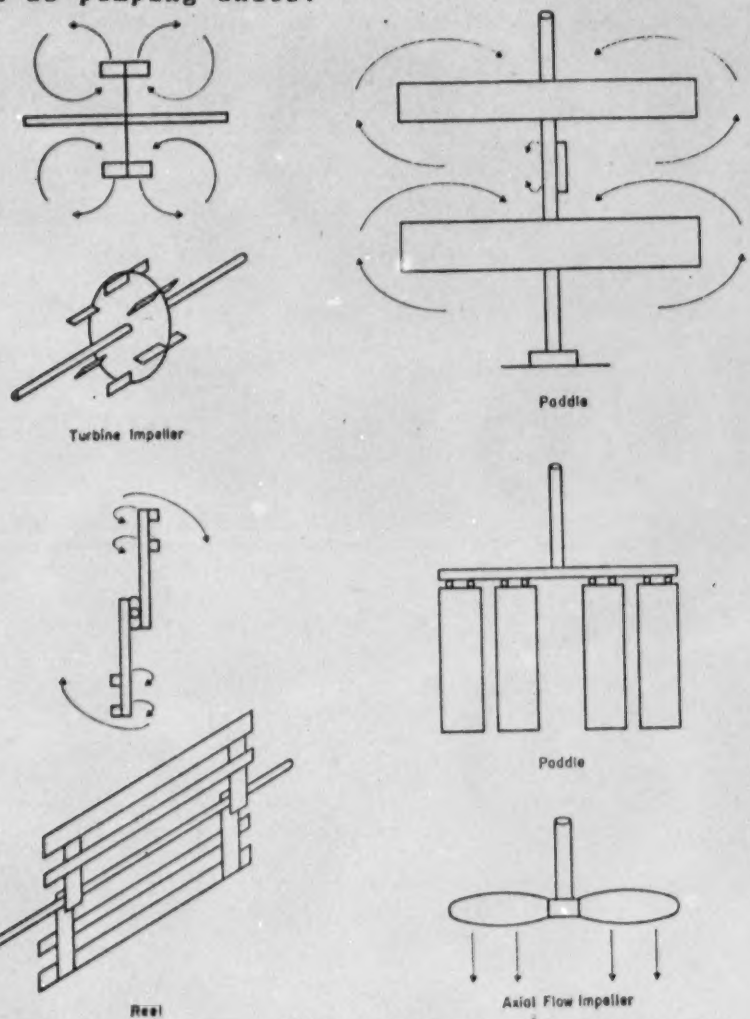


Fig. 1. Types of Agitators
The arrows represent the flow patterns created by the agitator units. Paddle and reel type units tend to impart a general rotary motion to the water, as well as some internal turbulence.

For small plants, valves may be used as basin inlet and outlet shutoffs, while for larger plants surface conduits may economically be served by slide or sluice gates. For cleaning, basin floors must be pitched toward the drain outlet. Hydrants for hose connection should be provided to facilitate cleaning. Drain valves, commonly of the mud valve type, are required. Drains should be sized to permit gravity emptying of the basin in 15-60 min. Means of access in and out of the basin should be provided; this is usually done by providing cast-iron manhole rungs in the wall.

Rapid Mixing

Where only a coagulant is used, or in a few other cases where sequence of application is not critical, rapid mixing may be obtained by injection of the chemical into a point of high-velocity flows, such as the suction of a low-lift pump. More commonly, however, rapid-mixing chambers are used. Where feasible, these should have at least two compartments so as to enable sequential application and dispersion of each reagent. Ordinarily, rapid-mix chambers are fitted with vertical-shaft rotary mixing devices such as paddle agitators or turbines. Where practicable, underwater bearings are avoided.

The sequence of addition of chemical for coagulation is often important, and unpredictable; multiple points of application of the chemicals are therefore required. The chemicals ordinarily used are a pH-adjusting compound, such

TABLE 1.
Characteristics of Rapid Mixing Devices

Type	Characteristics
Baffled	Not suitable where flow varies widely; loses 1-3 ft head; very little short circuiting
Mechanical mixer	Very effective; not affected by flow variance; little head loss
Air agitation	Useful if preaeration is required
Pump	Injection of chemicals ahead of a low lift pump; time brief; cost often low; no additional head loss

as lime or an acidic substance, the coagulant (normally aluminum sulfate or a ferric compound), and a coagulant or flocculation aid. Prechlorination treatment is commonly applied to water before or after the rapid mix, while activated carbon usually may better be added after the coagulant.

Characteristics of rapid mixing units has been to provide 10-30 sec. detention time with relatively high powered mixing devices. Where possible, the rapid mix should be a two-compartment unit.

The mixing facilities should be located so as to be convenient to the plant operator and as close as is feasible to the chemical handling, storage, and feeder facilities. In many instances, the rapid-mix chamber can be placed below the chemical feed floor. This means short chemical feed lines and may simplify handling of chemicals, like lime suspensions, which are difficult to handle.

Flocculation

After the coagulant has been introduced and diffused, the minute coagulated particles are brought into contact with each other and with the other particles present, by prolonged agitation, during which the particles coalesce, increase in size, and are packed to greater density. Velocities commonly used for flocculator agitators are from 0.6 fpm upward and detention times range from 20 to 60 min.

Too-high velocities will shear floc particles and prevent them from building up to a size that will settle rapidly. Too-low velocities fail to provide sufficient agitation to enable flocculation to become complete, and may fail to attain the desired compaction.

Floc may be broken up at points of increased agitation in locations like conduits or other points of restricted flow, or in filter beds, where the agitation may be sufficient to cause the floc to pass completely through the filter. Some good may be done by manipulating the physical facilities of the plant, such as changing flocculating intensity to improve floc strength, or reducing plant flow rate. More commonly and effectively, to increase floc strength, the use of chemical agents such as activated silica or polyelectrolytes is instituted.

Baffled flocculation basins, formerly widely used, are seldom installed today except where avoidance of mechanical equipment is important. They have a distinct advantage in freedom from short circuiting, but possess the disadvantage that mixing intensity is dependent on flow rate.

To control short circuiting in mechanical flocculators, at least three successive compartments should be provided. In addition, special attention needs to be given to the ports between compartments to further suppress short circuiting.

A number of satisfactory flocculator arrangements are shown in Fig. 2. It should be noted that design velocity gradients in ports and conduits should not exceed those in

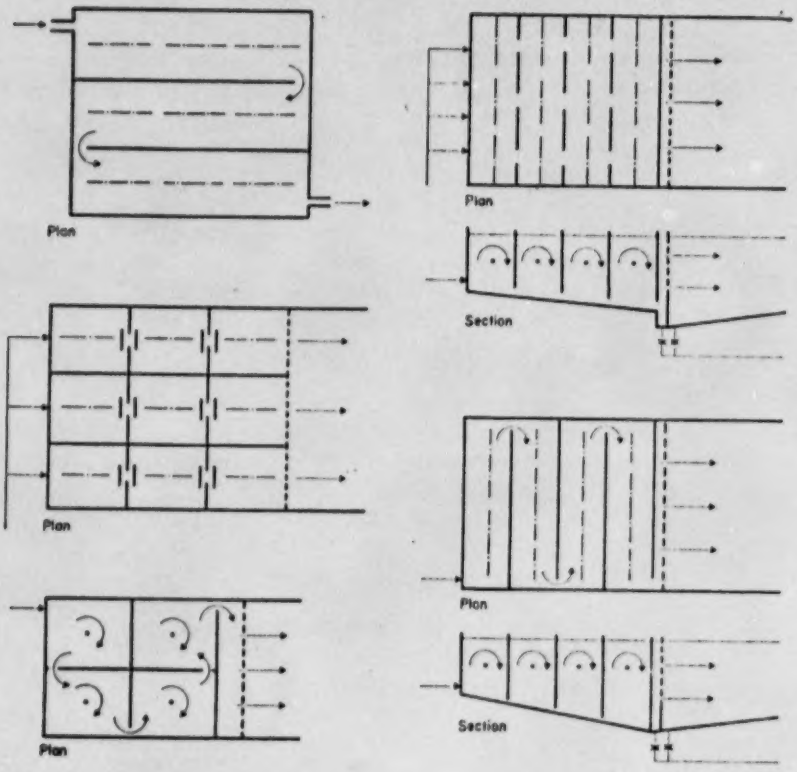


Fig. 2. Flocculator Layouts
Arrows represent the path of water flow. The easiest way to manage flocculated water is to build the flocculator and settling basin integrally, with a permeable baffle discharging the flocculated water into the basin to assure uniform horizontal and vertical distribution of settling basin inlet flow.

the flocculator basin if floc shearing is to be avoided. Care should be taken not to break up floc before settling; what happens after settling and before filtering is of much less importance. The easiest way to manage flocculated water is to build the flocculator and settling basin integrally, with a permeable baffle discharging the flocculated water into the basin to assure uniform horizontal and vertical distribution of settling basin inlet flow.

SEDIMENTATION*

Settling tanks (sedimentation tanks, sedimentation basins, settling basins, or clarifiers), are used in water treatment to reduce the amount of settleable solids suspended in water. Sedimentation is one of the most widely used processes in the treatment of water, second perhaps to chlorination.

Sedimentation usually finds application in two principal ways in water treatment: plain sedimentation and sedimentation following coagulation and flocculation or softening. Plain sedimentation is used to remove settleable solids that occur naturally in surface waters. These solids settle without any previous treatment. Plain sedimentation is usually used as a preliminary process to reduce heavy sediment loads prior to subsequent treatment processes such as coagulation. This preliminary sedimentation is often also referred to as presedimentation.

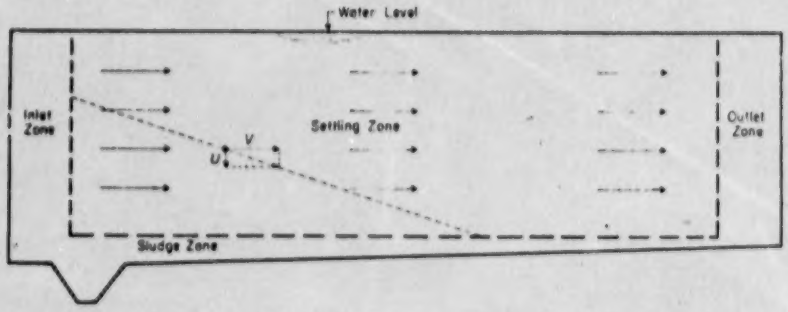


Fig. 1. Four Hypothetical Zones in a Rectangular Sedimentation Tank. The diagram shows the four hypothetical zones in a rectangular sedimentation tank, the flow distribution desired, and the theoretical path of a discrete particle.

Sedimentation following chemical coagulation and flocculation is used to remove settleable solids that have been rendered more settleable by chemical treatment, such as the addition of coagulants to remove color and turbidity and the addition of lime and soda ash to remove hardness. This type of sedimentation follows presedimentation (if used) and aeration, and precedes filtration. Flocculation and

*Source: Water Treatment Plant Design, published by The American Water Works Association, 1969; pp. 77-81

sedimentation are not distinctly separate treatments because there can be further flocculation in the settling tank, and they are sometimes referred to collectively as treatment by coagulation-sedimentation.

Zones in Sedimentation Tanks

Settling tanks have been traditionally divided into four zones for purposes of discussion, each zone having its characteristic function (see Fig. 1):

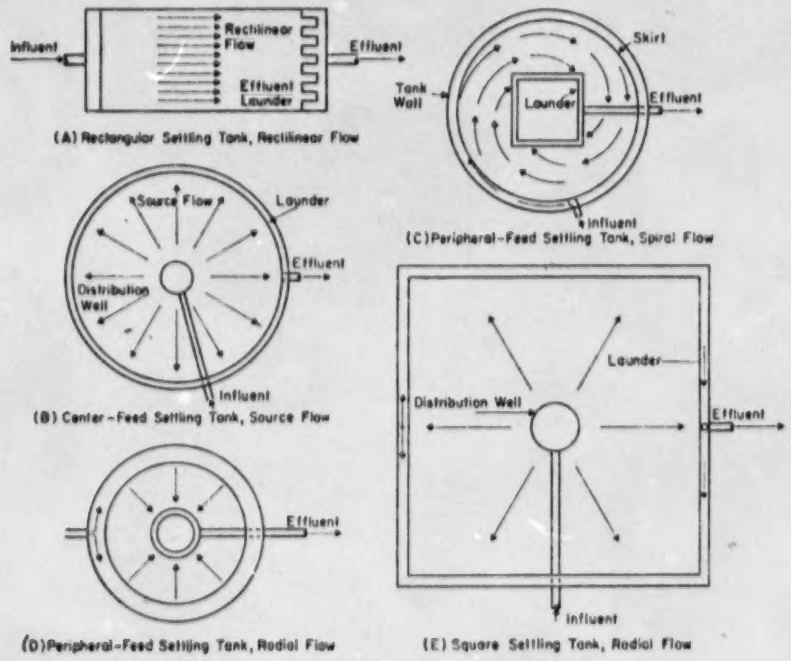


Fig. 2. Flow Patterns in Sedimentation Tanks Of the circular tanks, the one with center feed and radial flow, 2(B), is the only one commonly used today.

1. *Inlet zone*-to provide a smooth transition from the influent flow to the uniform, steady flow desired in the settling zone
2. *Outlet zone*-to provide a smooth transition from the settling zone to the effluent flow

3. *Sludge zone*-to receive the settled material and prevent it from interferring with the sedimentation of particles in the settling zone

4. *Settling zone*-to provide tank volume for settling, free from interference from the other three zones.

The functions of these zones are ideal in nature. If the inlet, outlet, and sludge zones performed as well as desired, the efficiency of settling tanks would be much higher than they are because the settling zone could provide practically undisturbed settling. In the past, these four zones have not been completely separated, and the settling zone is influenced considerably by the other three zones. In some poorly designed basins, the inlet and outlet zones take up so much volume because of overlapping with the settling zone that the effective settling zone is much smaller than intended in the design.

Types of Sedimentation Tanks

The effectiveness of a sedimentation tank depends on the settling characteristics of the suspended solids that are to be removed and on the hydraulic characteristics of the settling tank. The hydraulic Characteristics of a settling tank depend on both the geometry of the tank and the flow through the tank. Most sedimentation tanks used in water purification today are of the horizontal-flow type. Horizontal-flow tanks may be either rectangular or circular in plan. Circular, horizontal-flow tanks may be either center feed with radial flow, peripheral feed with radial flow, or peripheral feed with spiral flow; however, in current practice only the first is in common use.

In a rectangular tank, the flow is essentially rectilinear, or flow in which the flow lines are parallel and all in one direction (see Fig. 1 and 2A). In horizontal-flow tank design, the aim is to achieve as nearly as possible the ideal condition of equal velocity for all points lying on each vertical line in the settling zone (the ideal basin condition). This, in effect, would be complete separation of the four zones of the tank. This condition cannot be achieved because of differential friction drag and irregular tank currents. Flow usually enters one end of the tank through a perforated baffle or diffusion wall, travels the length of the tank, and then exits over some type of effluent weir.

The most common circular horizontal-flow tank in water supply practice is the radial flow tank. The flow in a center feed circular tank is essentially a point "source flow," the flow emanating from a single point, theoretically infinitesimal in size, and flowing radially outward in all directions (Fig. 2B). Theoretically, the velocity is infinite at the source and approaches zero at an infinite radial distance. In practice, flow enters through a conduit that passes to the center of the tank below the water surface. The inlet is usually a cylindrical baffle, sometimes perforated, that dissipates the inlet velocity. The water then flows radially toward the periphery of the tank where it exits over a peripheral weir or launder. The aim is to achieve uniform radial flow with decreasing horizontal velocity as the water flows toward the periphery. Sometimes, square radial flow tanks are used (Fig. 2E).

In the center feed circular tank, the flow is not perfectly radial but has definite vertical velocity components, downward at the distribution well and changing to upward near the peripheral launder. As indicated, both rectangular and circular sedimentation tanks are used in practice. The choice of type is usually based on personal preference with recognition of the fact that many sedimentation basins are now equipped with mechanical equipment for the continuous removal of settled solids.

FILTRATION *

Introduction

Filtration is defined as the passage of a fluid through a porous medium to remove matter held in suspension. In water purification, the matter to be removed includes suspended silt, clay, colloids, and microorganisms including algae, bacteria, and viruses. The particles to be removed have approximate size as follows, stated in millimicrons (a micron is 0.001 mm, and a millimicron is one thousand times smaller).

Material	*Particle size, millimicrons*
Silt.....	50,000
Bacteria.....	5,000
Viruses.....	50
Colloids.....	1-1,000

The Filter

As used in water treatment, a filter may consist of a thin porous layer of filter aid deposited by flow on a support septum, or a bed of granular nonporous material held in place by the force of gravity or by the direction of flow.

The most widely used units of the latter type are rapid-sand filters in which gravity holds the material in place, and in which the flow is vertically downward. The filter medium is usually supported on a gravel bed which is underlain by an underdrain system that collects the water into a pipe which conveys it to a filtered water chamber.

Carefully screened gravel is usually installed in a series of layers several inches thick ranging from coarser stones at the bottom to 0.1-in. particles at the top. The coarse material absorbs the energy of the high-velocity jets emerging from the underdrain system, and the diminishing size is intended to serve two functions: (1) to spread the flow uniformly under the entire sandbed area during backwashing and (2) to support the sand so that is will not pass

*Source: Water Quality and Treatment, A Handbook of Public Water Supplies, prepared by The American Water Works Association, Inc. and published by the McGraw-Hill Book Company, 1971. pp. 243-278.

downward out of the bed during filtering cycle. The filter is periodically cleaned with filtered water by reversal of flow and discharge of the sediment-laden water to a drain. Most rapid-sand filters are contained in concrete boxes and designed so that the upward flow of wash-water, with auxiliary scouring system, lifts the removed sediment out of the expanded filter medium and flushes it away to a point of disposal. Figure 1 shows a typical rapid-sand filter of larger size.

The filter media normally used in american practice are described by the following table:

TABLE -1 Properties of Filter Media Materials

Material	Shape	Density	Hardness*	Porosity, %	Range of effective sizes used, mm
Silica sand	Rounded	2.6	7	42	0.4-1.0
Silica sand	Rough	2.6	7	44	0.4-1.0
Crushed quartz	Angular	.2.6	7	53	0.4-1.0
Silica gravel	Rounded	2.6	7	40	1.0-50
Garnet sand	.....	3.1-4.3	6.5-7.5	.....	0.2-0.4
Crushed anthracite	Angular	1.5	3	55	0.4-1.4
Alluvial anthracite	Rounded	1.5	3	50	0.4-1.0

*Moh scale.

Sizes are normally determined by sieving, and usually expressed in terms of the effective size-the size particle which is exceeded in fineness by 10 per cent of the sample. The distribution of sizes is expressed by the uniformity coefficient, which is the ratio of the 60 per cent size to the effective size.

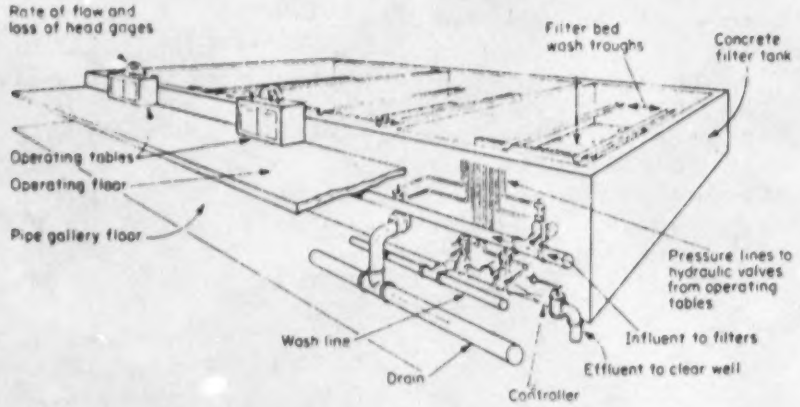


Fig. 1 Battery of three filters.

Pretreatment Effects

The traditional rapid-sand filter, contained sand of 0.5 mm effective size, 24 to 30 in. thick, operating at a 2 gpm/sq ft filtration rate, is not effective in clarifying water that has not received prior treatment. Because of this, flocculation of water prior to filtration is almost always employed. In most cases flocculation has been followed by sedimentation to reduce the quantity of material applied to the filter.

The most important characteristics of the flocculated water applied to filters are: (1) the completeness of the flocculation and (2) the strength of the flocs. If, due to deficiencies in plant facilities or underdosage of coagulant, the fine particles are not all entrapped in the floc, the filters will be unable to remove them. This will be so even with small-diameter media, low filter rates, thick beds, etc. Variations in such parameters have little effect on filter effluent quality when flocculation is insufficient. Because this so frequently happens, some observers have concluded that variations in these parameters are unimportant.

Sometimes that is so, but there are cases in which, though flocculation is complete, the flocculated matter penetrates through the filters. It lacks the strength or toughness to resist the shear forces that occur in a filter bed. When this condition occurs, sand size, porosity, bed thickness, filter rate, and other variables exert a profound effect on water quality, as will be discussed in the next section. For orientation in evaluating floc strength, the following comparative table on 0.5-mm sand, 24 in. thick, 42 per cent porosity, and filtration rates of 2 gpm/sq ft is presented:

Floc Strength	*Condition*
Very week	Breakthrough begins when the filter sand head loss is less than 2 ft of water
Weak	Turbid effluent begins after head loss reaches 2 ft but before 8 ft of water
Medium	No breakthrough, but penetration of floc into bed greater than 3 in.
Strong	Penetration of floc into bed less than 3 in.

Weak flocculation may be caused by a chemical spill of a material like phosphate into the source. One such event occurred in the Detroit River in 1958 and lasted 5 days. All plants along the river were affected.

Fortunately pretreatment techniques, including more intense mixing, reduction of short circuiting, and the development of flocculation aids have steadily improved in recent years. The following table illustrates recent trends in water treatment, including both pretreatment and filtration.

Year	Turbidity of applied water	Filtered water	
		Turbidity	Number of particles /ml
1920	30	5	10^7
1940	3	0.5	10^6
1960	0.3	0.05	10^5

THE FILTRATION PROCESS

Filter Behavior

The following description of the filtration process is based on observation of sand filters using an optical magnifier to watch floc particles and fine-colored tracer streams. Similar phenomena would be seen in other media, such as anthracite.

Floc particle size and strength ar· of basic importance to the filtration process. In the water applied to filters, floc particle size may range from 2 mm down to sizes less than 0.1 mm. In a filter containing rounded media, the pore opening sizes will range from 15 to 40 per cent of the particle diameter. Thus the pore openings in a bed of 0.5-mm sand will range from 0.1 to 0.2 mm in size. In coarse, angular media, such as 1.2-mm anthracite, because of greater porosity, pore openings are larger, ranging from 0.3 to 0.6 mm.

It follows from these dimensions that the larger floc particles can be removed by simple straining at the bed surface, but that much of the flocculated matter will pass into the bed and lodge within it. Unless the flocs are exceptionally strong, those that initially lodge in the bed by simple straining will subsequently break as the hydraulic gradient increases. Since breakage of the flocculated matter within the bed is inevitable, it is not necessary to handle

settled water gently. Rough treatment, such as tumbling over weirs or pumping seems to have no adverse effect on filterability of the applied water.

The flocculated material in the water passes into the filter bed through thousands of openings in each square foot of the filter surface and, by the end of a filter run, ordinarily lodges largely in the top 1 to 4 in. of the bed. When a clean filter is placed in service, nearly all of the floc particles pass into the bed. As the flocculated matter lodges between the sand grains beneath the surface, the free void area is reduced, and the bed offers resistance to the flow of the water. Conditions then begin to change. The rate of flow increases through the larger openings and lessens through the smaller and partly clogged openings. As a result, many of the larger passageways remain nearly free of deposited material (Fig. 2). As filtration continues, the smaller openings become so filled with the coagulated material they are almost closed. The number of openings at the surface per square foot of filter area is still very large, and there may not be an area as much as 1/2 sq in. without a hole. Gradually many of these holes stop feeding channels when the voids beneath the surface become so clogged that flow becomes impossible.

At the beginning of a filter run nearly all of the floc particles lodge in the sand within 1/2 in. of the surface. Particles that impinge on previously removed flocculated matter adhere to it. The opportunities for lodgement or attachment are very large, for with 0.50-mm sand each drop of water that passes through the filter has to pass 3,000 or more small openings between the sand grains.

If the sand grains are small in size, or if the floc is tough, the penetration of flocculated material beneath the sand surface may be small. This is illustrated in Fig. 2a. Figure 2b represents penetration of part of the coagulated material into the bed with a fairly large portion of it remaining at the surface. Figure 2c depicts continuing penetration into the bed through channels. Figures 2b and c represent conditions which are expected to take place in a rapid-sand filter bed. These figures are diagrammatic; the channels are actually quite crooked. To obtain filter runs of reasonable length with sand beds, the penetration of coagulated material into a single-media bed should be from 2 to 4 in. When there is little penetration of the material into the filter bed, as shown in Fig. 2a, the filter loss of head increases rapidly, and the filter runs are too short for practical operation of the filters. When penetration is greater, flocs pass down into coarser underlying layers, and there is danger of breakthroughs.

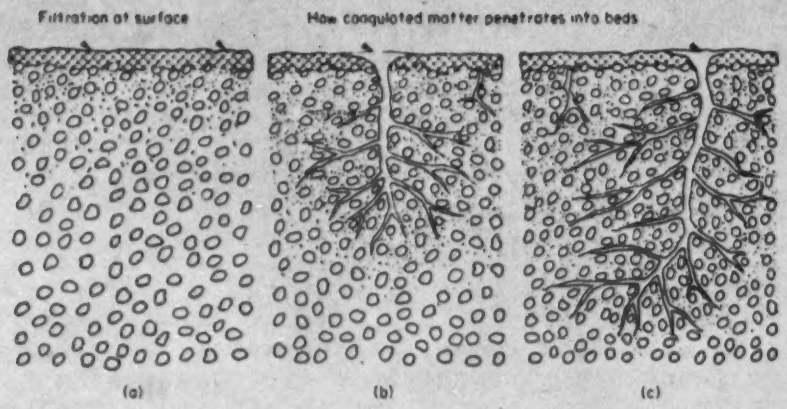


Fig. 2 Sketches showing what takes place in a filter bed.

There is little or no deposition of flocculated material in the channels where velocities are high. The sediment-bearing water moves down the channels until it reaches voids that have not been filled with the coagulated material. It then spreads out, the velocity reduces, and lodgement of flocs again takes place.

When the voids in the sand around the end of a channel have filled sufficiently to increase the resistance to flow, previously deposited floc shears, and new channels open up through previously unperforated areas and conduct the water to unclogged sectors. These new channels are caused by the increasing hydraulic gradient, which causes increased shear stress. The process continues to repeat itself. As the loss of head through the filter increases and the flocculated material clogs to a greater depth, the channels through the surface become fewer. Some water also enters the bed by seepage through the surface layer. The part that does this is small in comparison to that entering through channels.

The probability of a floc particle striking the surface of the filter medium is influenced by sand size, porosity, filter rate, temperature, and density and size of floc particles. The adherence of the particles is affected by colloid chemical forces which include the age of the floc, temperature, coagulant concentration, type and concentration of anoins, and pH.

Negative Head and Air Binding

Some filtration plants have only 4 to 5 ft of water above the sand surface and have occasional problems of air binding. Air dissolves in water at or near the saturation point. When the pressure is reduced to less than atmospheric pressure below the surface of the sand, air comes out of solution, and air bubbles accumulate below the sand surface, rapidly

increasing the resistance to flow through the sand bed. Maintaining a high level of water above the filters reduces the head at which air begins to accumulate in the sand. Air binding in filters causes sand loss at the start of the backwash due to violent agitation from the entrapped air and requires that the filter must be washed before it reaches its normal time of service. In many water plants, air binding occures only during the spring season when the surface water is in the stage of "warming-up" and is supersaturated with air.

CLEANING THE FILTER

When a filtering cycle has been concluded because of the development of a head loss so high that the filter can no longer produce water at the desired rate or because of depreciation of effluent quality due to terminal breakthrough, it must be cleaned. This usually involves: (1) closing the inlet valve, (2) filtering down to near trough level, (3) closing the filtered water effluent valve, and (4) opening the drain valve. Step 2 is sometimes omitted when there is need for haste. The filter is now ready for washing.

In some plants filters are cleaned by backwash alone, while in other surface-wash agitation is also used. Most European plants use an upward air scour together with a reduced backwash rate, but the success of this process seems to be greatest when the filter medium is coarse sand-0.8 mm in size or larger. Such coarse sand is seldom used in the United States.

The Washing Process

As the backwash valve is opened, the sand surface rises and a heavy concentration of coagulated material previously filtered from the water begins to overflow the washwater troughs and drains out the waste pipe. Within 3 or 4 min the water clears sufficiently for the backwash to be terminated. If the washing is continued a little longer, the surface of the sand may be seen, first dimly then very clearly, within 30 to 60 sec. At this time the sand level is some inches above its original level and is in vigorous agitation, boiling up in some areas. At the same time there is rapid and erratic lateral movement in some areas and slower movement elsewhere, first in one direction, then another. The movement is much more rapid than can be accounted for by the calculated average upward velocity of the backwash water.

Repeated observations of filter backwashing in a glass-walled filter having 10 sq ft of sand surface have shown that,

with slow opening of the backwash valve, the sand bed gradually expands, beginning at the top of the bed, then progressing downward. When the backwash valve is fully open, the sand surface rises to its maximum height during the backwashing period. Usual backwash rate is 15 gpm/sq ft. Higher backwashing rates are used in many filtration plants.

As backwashing begins, the sand grains do not move apart quickly and uniformly throughout the bed. Time is required for the sand to equilibrate at its expanded spacing in the upward flow of washwater. If the backwash is turned on suddenly, it lifts the sand bed bodily above the gravel layer, forming an open space between the sand and gravel. The sand bed then breaks at one or more points, as shown in Fig. 3, causing sand boils and subsequent upsetting of the supporting gravel layers. This then requires frequent rebuilding of the gravel section.

It is essential that the backwash valve open slowly. The time from start to full backwash flow should be at least 30 sec and perhaps longer and should be restricted by devices built into the plant. This is frequently done by means of an

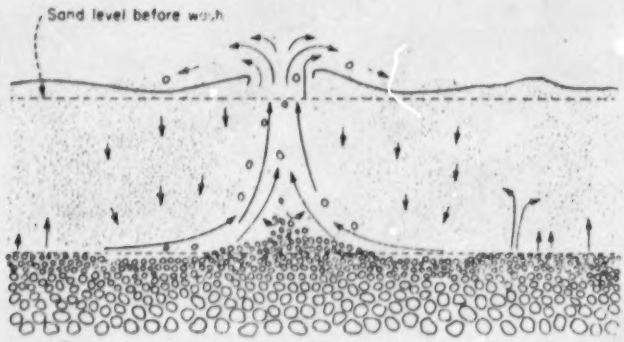


Fig. 3 Sand boil at beginning of wash.

automatically regulated master wash valve, controlled hydraulically or electrically and designed so that it cannot open too fast. If, in a given plant, such a valve cannot be provided, a speed controller should be installed on the operator of each washwater valve.

The most destructive filter washing blunder is to turn the backwash on quickly when the bed has been drained. Gross gravel disturbance results and rupture of the filter underdrain system due to water hammer has resulted in many cases, particularly with false-bottom-type underdrains.

The surface wash, commonly used in plants where the backwash cannot completely clean the filter, is of two types: the fixed-jet system and the filter-sweep type. Ordinarily

both employ jets of about 1/8 in. diam, discharging at an angle of 15 to 30° below the horizontal, operating at pressures of about 75 psi. The jets are ordinarily located about 2 in. above the unexpanded sand surface. The filter sweeps are designed to discharge about 0.5 gpm/sq ft, while the fixed-jet type uses 2 to 4 gpm/sq ft.

A Filter sweep is served by a vertical pipe bringing high-pressure water downward in the filter box. This pipe terminates in a swivel fitting, out of which project two horizontal pipe arms at 180° positions. Nozzles on one side of one arm and on the opposite side of the other cause the sweep to rotate when the flow is turned on. A typical fixed-jet system is shown in Fig. 4.

The surface wash is normally turned on before the backwash, and frequently a rate of wash that will barely expand the sand bed is used for several minutes to allow the surface wash to work hard on the top of the bed where mud balls form. This is then followed by a few minutes of higher backwash to flush out the bed. When the surface wash is used with anthracite, it is important to expand the bed to a level well above the jets. It has been observed that anthracite is more easily thrown out of the filter by the surface wash turbulence than is sand. Expanding the coal beds above the surface wash seems to reduce the loss of coal.

Mud balls sink more easily in anthracite beds than in sand beds and tend to form or accumulate at the coal-sand junction. To offset this characteristic, there is a trend toward installation of the supplemental wash system within the coal bed at an elevation about 6 in. above the sand. This requires check valve nozzles to keep the media out of the nozzles.

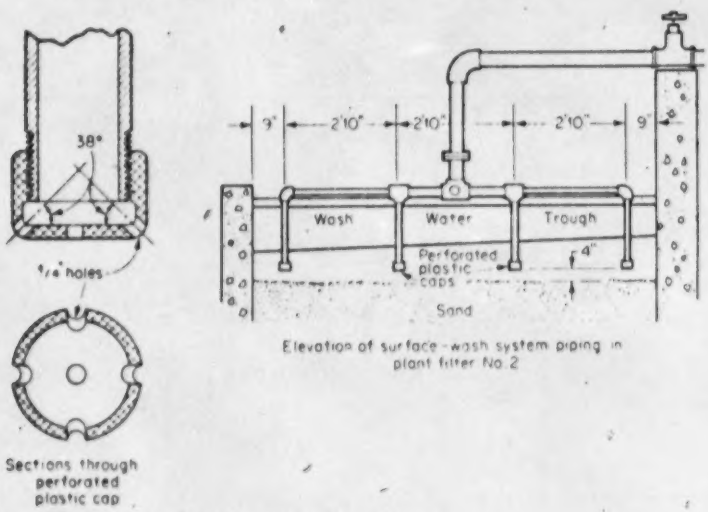


Fig. 4 Details of fixed-jet surface-wash piping

Jet Action

Just as channels form in the sand bed during filtration, the upward flow from the gravel is never completely uniform and, as a result in some parts of the expanded sand bed the water and sand travel upward at rates higher than the average backwash velocity, and at other places the sand actually travels downward. Even with the most careful gravel selection and placement the gravel is distrubed in some degree by a natural tendency toward channeling. This leads to jet action at the sand-gravel junction, as illustrated in Fig. 5.

Jet action is a natural phenomenon which takes place wherever water flows upward through porous material with a velocity that partly suspends the material. It occurs wherever fine particles overlie coarser ones, and the upward velocity of the water partially expands the fine material but not the coarse. The size and specific gravity of the material merely affect the velocity and the size of the jets and not their occurrence. The jet action is readily observed in a glass-walled filter.

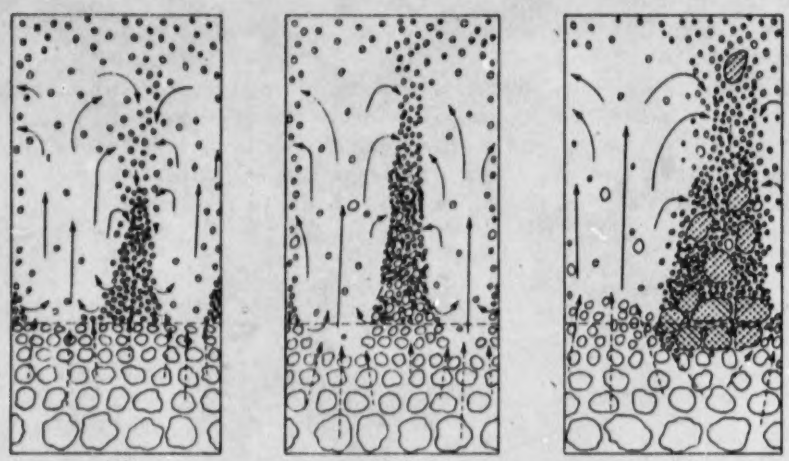


Fig. 5 Jet action at the sand-gravel interface.

An upward flow through a graded gravel bed at backwash rates exceeding 25 gpm/sq ft will not move any of the gravel particles unless sand is present on top of the gravel. The presence of the sand greatly increases the mobility of the gravel.

The head loss through an expanded 24-in. sand bed is approximately 2.0 ft, which corresponds to the weight of the media minus the weight of the water it displaces. Such a pressure beneath the sand has enough energy to cause localized flow velocities of about 10 fps, a flow rate 300 times greater than the average backwash rate. Such velocities can be very mischievous in a filter.

In some cases the jet velocity is so great that it will move small gravel particles several diameters larger than the sand grains adjacent to the gravel. With a normal backwash rate, the average upward velocity of the water through the gravel should be less than 0.1 fps. The velocities of the jets have been observed to be more than 10 times the average upward velocity through the area occupied by the sand.

Each jet must be fed with sand, so there is a downward or lateral movement of the sand around the jet. In a sand jet the sand occupies about 10 to 15 per cent of the volume of the sand and water. Where it is falling, the sand occupies about 30 per cent of the volume. The resulting difference in density between these two adjacent mixtures provides the force that sustains the rapid velocity in the jet.

These jets of water and sand are constant disturbers of the fine-gravel layers, and since the vast majority of filter beds are gravel-supported, the jets are a prime cause of the need for filter rebuilding. The jets cause lateral displacement of the gravel. This lateral movement is much greater when backwash rates exceed 15 gpm/sq ft. Sometimes several minor adjacent jets will merge to form a single stream operating at a high enough velocity to carry it to the top of expanded sand. There the boil may appear to be 12 in. or more in diameter. It generally occurs in the same place at each backwashing. Such a boil moves very coarse gravel and usually presages a failure to support the sand. See Fig. 6.

In some instances, jet formation is stimulated by uneven distribution of backwash water; the jets tend to form where the backwash rates are higher. When this happens, a peculiar phenomenon occurs: the displacement of the gravel allows sand to pass downward into the underdrains, clogging them so that the area of originally high backwash rate becomes one of very low flow. The areas of jet formation then migrate laterally to new areas of high upflow, and ultimately a nearly complete reversal of the jet pattern predicted by hydraulic computations is found.

Probing the Gravel

To determine whether there is serious gravel movement, filters should be probed annually or more frequently if there is reason to be suspicious. There are two methods used: (1) with a 1/4-in. metal rod while the filter is at rest, and

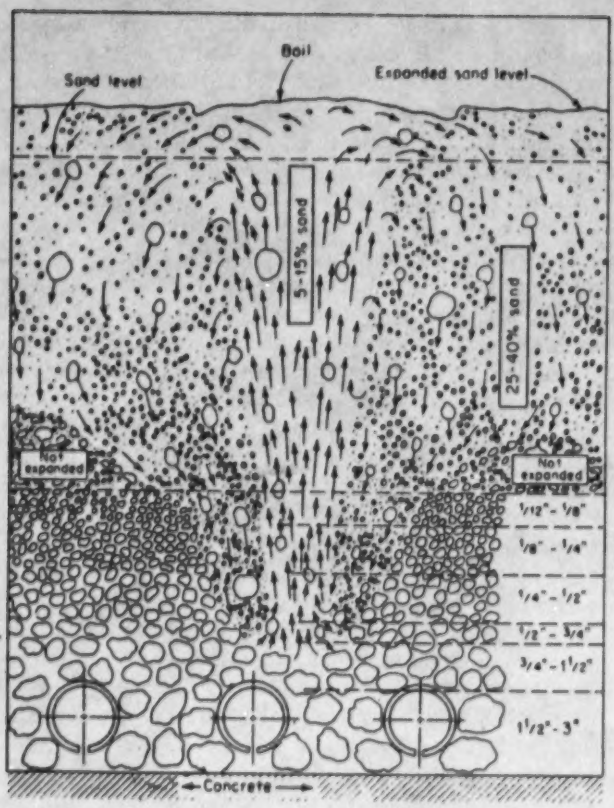


Fig. 6 Diagram of sand boil in filter bed.

(2) with a special probe during backwashing. The former procedure can be carried out with the water level at its normal elevation, at trough elevation, or with the filter drained. Either the water surface or the sand surface is used as a reference point. If the sand surface is not almost perfectly level, uneven distribution must be assumed. The gravel is probed on a horizontal grid system, depths to gravel recorded, and a contour map can be drawn if desired.

For probing during backwashing, the thin rod may be used, or a special sounding device may be employed. This uses a steel or aluminum pole equipped with a 6-in. circular heavy-grade 1/4-in. mesh screen welded to the end of the pipe or rod. The pipe should be of sufficient length so that the person making the test can stand in the washwater trough and conveniently measure the depth to which it penetrates. This is usually done using a low backwash rate that is sufficient to suspend the sand so that in probing, the screen rests on the top gravel layer. With such a probe, the check of the gravel layer height in the filter is usually made at intervals of several feet along each washwater trough.

Mud Ball Concentration

In all plants a periodic check should be made for the accumulated mud ball concentration. Where experience shows that the mud ball forming tendency is low, the check may be annual.' Where the problem is severe, a monthly check may be desirable. In the early stages of filter deteriorations, the concentration of mud balls is greatest in the top of the bed. The mud ball determination is therefore made on the top 6 in. of the bed.

Formation of Mud Balls

With deficient washing, the compacted material accumulates in the bed and grows increasingly compact. The particles grow to larger size by adhering to each other and to sand grains at the surface of the bed. Newly formed mud balls remain at the filter surface when the washwater is cut off.

The mud balls grow increasingly compact and eventually reach a density great enough to cause them to sink into the sand during the washing period. While they are forming and being compacted, they are also being worn away gradually by abrasion by the sand during the washing periods. Some of them clump together in the bed and form mud deposits at the bottom of the sand bed or against the sidewall of the filter. If the rate of wearing away is as great as the rate at which the mud balls are built up, the volume of mud balls in the filter does not increase.

The rate of wearing away of clogged masses and mud balls is fairly uniform throughout the year and from plant to plant, but the rate of mud ball formation varies greatly from place to place and from time to time. In many plants, the concentration of mud balls in the filters diminishes in winter.

After a filter run it may be noted that some of the material filtered from the water is not removed from the filter at the usual rate of backwashing. Part of the mud or coagulated material has become compacted during filtration. While the density of the compacted particles is less than that of the sand grains, the particles are much larger, and this gives them a settling rate through water nearly as great as that of sand. If the mud particles are not broken up by an agitating force much greater than that produced by backwash alone, these particles are not removed.

Bed Shrinkage During Filtration

When the sand grains in a filter are clean, they rest directly against other grains in the bed, and unless there is some vibration of the filter, there will be little compacting of the bed as the loss of head increases. If the

sand grains are covered with a soft coating, the bed compresses as the loss of head increases. Cracks may form as shown in Fig. 7.

Measurements of vertical compaction have been made in a number of filter beds. The measurements were made with a light vertical rod supported by a flat base on the sand surface, placed after each wash. Movement of the rod was periodically measured from a reference point at the top of the filter.

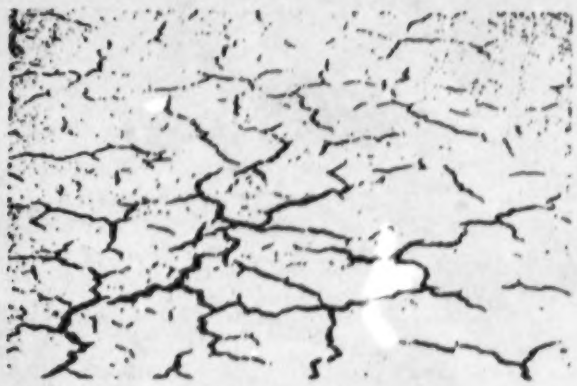


Fig. 7 Cracks in filter beds.

Pulling Away from Sidewalls

Settlement of the beds contributes to certain other filter bed troubles, for it allows beds to pull away from the sidewalls and at times permits cracks to open as shown in Figs. 8 and 9. Filter beds pull away from the sidewalls only when there is substantial contraction or settlement of the bed. Horizontal filtration begins to take place through the openings along the sidewalls, and it compresses the bed laterally. If the sand grains are so clean that the vertical compressibility of the bed is small, the bed cannot be compressed laterally. Cracks perhaps 1/8 in. wide may occur at the surface, and 2 to 4 in. below the surface with fairly clean sand, but no sidewall cracks will form.

Years ago, many filter beds pulled away from the sidewalls. At the ends of filter runs, some of them had pulled away from the sidewall as much as 1 in. at the top of the bed. By probing with a thin steel sheet down along the sidewall or by digging the sand away and observing the depth to which there was side filtration, as shown by the formation of a layer of mud near the wall similar to that at the surface, it was found that some of the sidewall cracks extended downward three quarters of the depth of 24-in. sand beds.

In plants where the sand accumulates a substantial coating, sidewall cracking cannot be prevented by backwash alone, even at the rates above 15 gpm/sq ft. Supplemental agitation appears to be the only means of keeping filter beds clean enough.

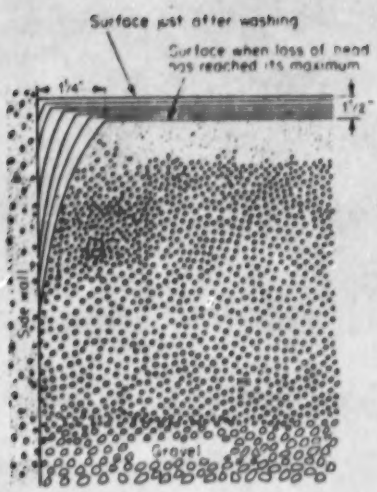


Fig. 8 Cracks along sidewalls of filters.

Cracks along the sidewalls of filters are objectionable because: (1) finer media at the top of the bed, which is the most effective part of the bed, are bypassed; and (2) clogged areas are caused to form along the sidewalls.

Clogged Areas

For the formation of clogged areas there must first be an accumulation of mud or mud balls in the filter. This is succeeded by shrinkage of the bed as the loss of head increases.

There is a tendency for the mud balls near the surface of a filter to clump together during the washing process, especially where the expansion of the bed is not more than 20 to 30 per cent. This is more pronounced near the sidewalls than in other parts of the bed. If a clump of mud balls that is drifting about in the filter during washing moves over to the sidewall, it frequently remains there and grows by accretion until it becomes a clogged mass as shown in Fig. 10. Additional clogged masses

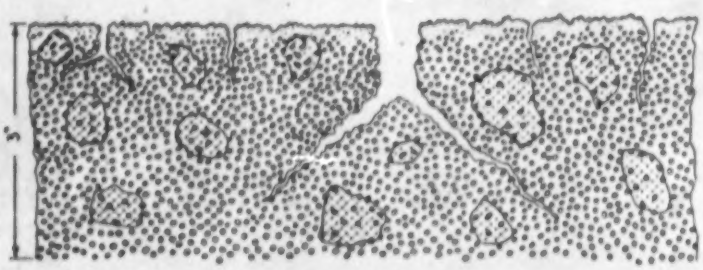


Fig. 9 Sketch showing typical surface cracks in top 3 in. of filter beds.

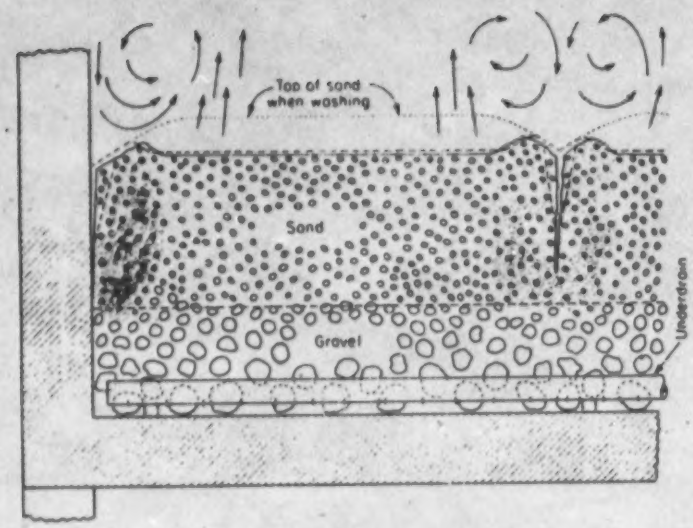


Fig. 10 Clogged areas in a filter bed.

can form in other parts of the bed, as indicated in Fig. 10.

Figure 10 is a sketch illustrating both typical sidewall clogging and clogging in another part of the bed. The sidewall-clogged mass rests upon the gravel and does not adhere to the filter sidewall. It leans away from the sidewall as the loss of head increases, sometimes opening a crack all the way to the gravel. There is some side filtration through the clogged mass, especially in the upper part where the sand usually is not badly clogged, even though the mass is not agitated much during the washing because of the impermeable mass beneath it. There may be a very gradual displacement of this sand. The clogged mass moves against the sidewall during the washing period and is pushed away as the loss of head increases on the filter. In this condition the filter fails to do a satisfactory straining job.

Jet action helps pile up the mud balls at the gravel surface. Such pileups in turn accentuate the jet action. Prevention of mud ball formation by use of a surface wash at the top of the sand bed precludes the accumulation of mud balls at the gravel surface and thereby reduces the tendency of jet action to disrupt the filter bed.

The accumulated sediment which can be observed in the clear water reservoirs of many filtration plants is proof that suspended matter is getting past the filters. This is often due to shrinkage which leads to cracks along the sidewalls of the filters or cracks within the bed and to clogged masses in the beds. In some instances, such a condition constitutes a menace to health. In any event, the passage of any coagulated matter through the filter bed is objectionable and should be avoided even at considerable cost.

Pressure Sand Filters

Pressure filters are based on the same principle as gravity-type rapid-sand filters, but the underdrains, gravel, and sand are placed in a cylindrical tank, and the water is passed through the filter under pressure. In pressure filters the tank axis may be either vertical or horizontal. Filters of this type are intended for use where raw water is supplied under pressure and where it is desired to filter and deliver the water without further pumping. A cross section of a pressure filter is shown in Fig. 11.

Finished water from a pressure filter requires as careful pretreatment and as good a quality of applied water as would be necessary for finished water from free-surface filters. The extent and character of pretreatment are, of course, governed by the quality of the effluent desired.

Pressure filters are subject to the same operation difficulties as afflict standard rapid filters, except that air binding rarely occurs. Most of the troubles encountered are a result of careless operation or improper application of water by the operator, both inherent in the nature of these filters. Their use for the production of a domestic water supply is not approved by some authorities.

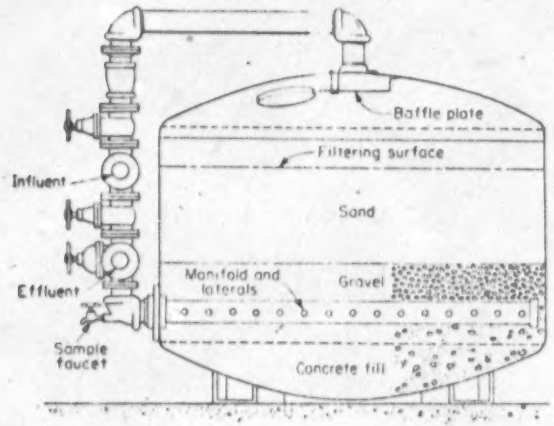


Fig. 11 Cross section of typical pressure filter.

CHEMICAL COAGULATION & FLOCCULATION*

Large, heavy particles suspended in water will settle out quite readily, but smaller lighter particles settle very slowly, or in some cases not at all. Chemical coagulation consists of treating the water with certain chemicals to bring the non-settleable particles together into larger, heavier masses of solid material, which are then comparatively easy to remove. These masses are called "floc".

The practice of coagulation includes several operations, discussed below, because each of them involves different considerations. The first step in the process consists of *feeding* one or more chemicals to the water. Secondly, *mixing* is necessary, so that the chemicals are rapidly and evenly distributed, and all parts of the water will be equally well treated. During the mixing, or immediately afterward, certain chemical reactions occur. Some of the reaction products are insoluble, and they begin to precipitate as solid particles. The term *coagulation* is sometimes used to refer specifically to these chemical reactions and the beginning of the formation of the floc. Since the same word is also used to mean the total overall process up to sedimentation, it must be used rather carefully to avoid confusion. The final step in the process is *flocculation,* which refers to gentle agitation of the treated water for a period of time. This favors the collision of the small floc particles with each other and with the other suspended particles in the water. This causes them to stick together and grow into large, readily settleable masses. Again, the word flocculation may have two slightly different meanings. In theoretical discussions it may mean the growth of the floc particles. In plant practice it more often refers to the gentle agitation of the water which brings about this growth. *Sedimentation,* generally, follows flocculation, but is usually considered a separate process and not a part of chemical coagulation. It refers to the removal of the floc from the water by settling in basins especially designed for the purpose.

Detailed steps in the coagulation-sedimentation process have changed during the past several years, and for this reason confusion still exists regarding such terms as "mixing", "coagulation", "flocculation", "sedimentation" and others. Insofar as this discussion is concerned, "mixing" refers to the rapid, uniform distribution of a coagulant or other chemical in the water being treated before chemical reactions have occurred to any marked degree. "Coagulation" refers to the physical-chemical changes which take place between the soluble coagulant and the alkalinity in the water to form precipitated or incipient floc. "Flocculation" refers to the gentle agitation of a coagulant treated water for an appreciable period of time to foster the coagulation reactions and to provide conditions favorable for the flocculent material to meet and adhere together into large floc masses. The term "sedimentation" refers to the settling of floc in basins specifically designed for that purpose.

*Source: Manual of Instruction for Water Treatment Plant Operators, New York State Department of Health, Health Education Service, P.O. Box 7283, Albany, N. Y. 12224, Chapter 7.

Chemicals Used for Coagulation

Several different chemicals may be used in coagulation, depending upon the characteristics of the water being treated. In some waters a combination of two or more chemicals produces better results than any one chemical does alone. Usually, to decide which chemical or combination should be used, it is necessary to perform coagulation tests in the laboratory. These tests are described later in this Appendix.

Aluminum sulfate. Filter alum or merely alum is the most commonly used coagulant in water treatment. It may be purchased in solid form, or as a solution called "liquid alum". "Activated alum" contains about nine percent sodium silicate. This improves the coagulation in some waters. "Black alum" is alum containing activated carbon.

Sodium aluminate. "Sodium aluminate" is a much more alkaline compound than alum. When added alkalinity is found to be necessary for the best coagulation, sodium aluminate may be substituted for all or part of the needed alum dose.

Iron salts. The iron salts most commonly used as coagulants include ferric sulfate, ferric chloride, ferrous sulfate (also known as copperas), and chlorinated copperas. These compounds often produce good coagulation when conditions are too acid for best results with alum. Sometimes the particles are best removed under acid conditions and iron compounds give better results.

Coagulant aids. These materials do not produce coagulation when they alone are added to the water, but improve the results when they are used with a coagulant. Several of the chemicals used in this way are either acid or alkaline compounds and are used to adjust the pH for best coagulation. These include lime, sodium carbonate (known as soda ash), sodium hydroxide (known as caustic soda or lye), and sulfuric acid.

Other coagulant aids have little or no effect upon the pH, but enter into the coagulation process. Some of them are believed to act by providing solid surfaces where teh first formation of floc can begin more easily. Materials used for this purpose include certain clays (such as kaolinite and bentonite), sodium silicate, and activated silica. These materials may also add weight to the floc and improve sedimentation.

Still others are believed to react with the fine particles in the water and assist in bringing them together into larger and heavier masses for settling. Coagulant aids of this type have molecules which consist of long chains of atoms, with many reactive groups scattered along the length of the chain. These are mostly artifical products. Those known as "synthetic polymers" or "synthetic polyelectrolyes" are entirely man-made. Others are manufactured from starch or cellulose. The molecules of starch and cellulose are already long chains and in manufacturing the reactive groups are added.

Chemical Application

There are a number of chemical compounds which are used as water coagulants, but aluminum sulfate, commonly called alum, is most generally used. Alum is granular powder-like material which is readily soluble in water and is easily applied as a solution or as a dry material. Reactions between alum and the natural constituents in various waters are influenced by many factors and it is good operation practice to determine the required amount of coagulant to be added by trial or experiment.

Normally, the best coagulation results are obtained with an alum dosage from 10 to 50 ppm, with the optimum dosage being obtained through the use of the so-called "jar test". This technique consists of adding known amounts of a coagulant into several jars of the water to be treated, gently stirring this mixture for a definite period of time, and observing the quality and settling characteristics of the floc.

Sometimes a coagulant dosage is given in grains per gallon (gpg) or more conveniently, in pounds per million gallons (lbs/mg), the relationship between these units of measure are illustrated in Table I which may be used to convert dosages from one system of units to another.

TABLE I

Converting from	*Multiplication factor to get*		
	gpg	*ppm*	*lbs/mg*
Grains per gallon (gpg).	1.00	17.1	143
Parts per million (ppm).	0.0585	1.00	8.34
Pounds per million gallons (lbs/mg). .	0.007	0.12	1.00

Examples:
1. Express a dose of alum of 0.6 gpg in terms of ppm and lbs/mg.
   0.6 x 17.1 = 10.26 ppm. 0.6 x 143 = 105.8 lbs/mg
2. Express a dose of 30 ppm in terms of gpg and lbs/mg.
   30 x 0.0585 = 1.75 gpg. 30 x 8.34 = 250.2 lbs/mg.
3. How many pounds per day of alum would be required to treat 2.5 mgd with a dose of 25 ppm?
   25 x 8.34 x 2.5 = 521.3 pounds per day.

Coagulants are usually fed by a machine which can be set to deliver a known amount during a certain period of time. The machine may be calibrated in convenient units, such as pounds per twenty-four hours. There are available many types of machines or chemical feeders. A brief description of some types will suffice. Some machines feed alum in the dry form either directly or indirectly to the water treated. Usually the dry alum is fed at a known constant rate to a small tank, or "solution pot", where it is suspended in water. The resulting slurry is added to the water. Solution feeders, on the other hand, consist of tanks to hold solutions of known strength and a means for applying known amounts of the solution to the water being treated.

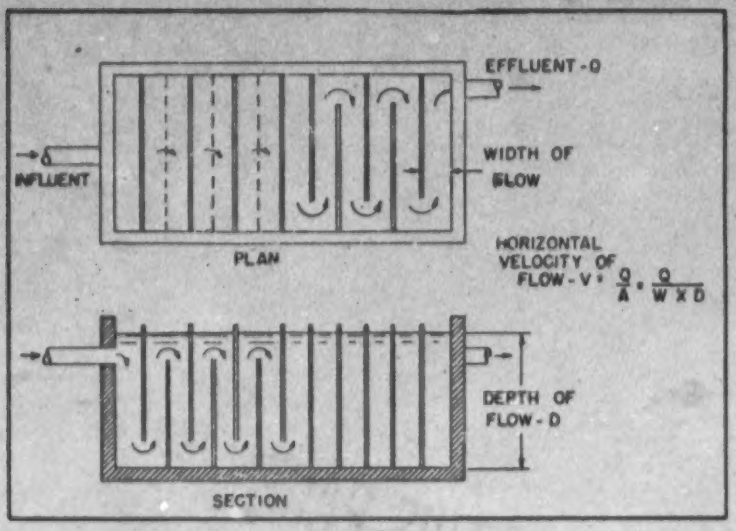
"Mixing" is necessary to provide rapid and uniform dispersion of the alum throughout the water being treated. It may be done either mechanically or hydraulicly in special tanks, in sections of other tanks, or in piping systems. The fundamental principle is the violent agitation of the water with the applied chemical for a short period of time. This may be accomplished either by motor driven propellers or baffled channels to create turbulent flow conditions. Contrary to popular belief, centrifugal pumps in themselves do not provide good mixing as their efficient performance depends on a minimum amount of turbulence as the water passes through them. Valves, elbows, and other devices normally used in conjunction with pumping operations may cause adequate turbulence for satisfactory mixing.

Flocculation takes place following mixing, usually in a single tank with a detention period between fifteen and forty-five minutes. During this period the water is gently agitated to make floc particles. Bacteria and suspended solids meet and adhere together into large masses. The physical-chemical mechanism by which this is accomplished is very complex and beyond the scope of this discussion. Suffice it to say that only by this gentle agitation will the coagulated particles become large enough to settle readily. Generally, soft waters of low mineral content coagulate best over a narrow range of pH values, between pH 5.8 to 6.4, whereas harder waters, such as those from the Great Lakes, coagulate quite readily at pH values of 6.8 to 7.8. Under normal conditions the reaction between alum and the alkaline materials usually found in a water supply are quite effective for the removal of turbidity and this is accompanied by the absorption of a moderate amount of color. Water with high concentrations of color, greater than about 30 ppm, require that the coagulation reaction be in the "acid zone" of pH value about 5.0 to 6.0. In this range a more complex action takes place to form what is termed a "color floc" instead the conventional aluminum hydroxide floc.

Normally, there is sufficient alkalinity present in the water to complete the coagulation process. At times, it is necessary to add alkalinity, in the form of lime or soda ash. When it is necessary to coagulate in the "acid zone" in order to remove color, an acid may be added to obtain the proper pH value. Such waters are quite corrosive and must be subsequently treated with an alkali to prevent corrosion from occurring in the distribution system.

The gentle agitation that is essential in flocculation may be accomplished either hydraulically or mechanically. The most common hydraulic method is the well known baffled basin, in which the water flows "around the end" or "over and under" baffles. Unfortunately, these baffles are not readily adjustable, and the degree of agitation depends upon the rate of velocity of the water. Since the optimum degree of agitation varies, this lack of flexibility is undesirable. Flow velocities between baffles from 0.3 to 1.0 feet per second usually give reasonably satisfactory results.

Figure 1

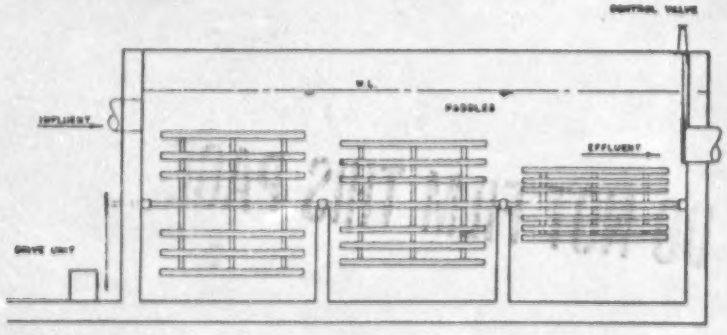


BAFFLE FLOCCULATION BASIN

The present trend is away from the use of baffles in flocculation tanks. In their place mechanically driven equipment is installed to provide the required agitation. The most common type of equipment consists of power-driven paddles or agitators so proportioned that appreciable but not undue agitation is produced. The speed of rotation can be controlled and the equipment operated to give the optimum degree of agitation regardless of the characteristics or quantity of water being treated or type of coagulant being used. The paddles may rotate on either a vertical or horizontal axis, and either longitudinally or at right angles to the direction of flow. Sometimes, several paddles are operated in series and the first paddle is rotated at a greater speed than the succeeding ones. Modern practice suggests sudden violent agitation as the coagulant is added with a gradual decrease in turbulence in each successive step through the entire process of "mixing", "flocculation" and sedimentation". Figure 2 illustrates a mechanically driven paddle type flocculation basin.

Essentially, the control of flocculation basins consists of regulating the amount of coagulant that is added as well as the degree of agitation in order to secure the most effective floc formation with a minimum coagulant dosage. At times, it is desirable to use coagulant aids in order to produce a floc which settles readily. It is good practice to equip the outlet end of the basins with submerged lights in order to permit observation of the floc that is formed. Properly coagulated water should show visible floc in clear water, like snowflakes in clear air, as contrasted to cloudy water or foggy air.

Figure 2



MECHANICAL FLOCCULATION BASIN